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USING A GIS TO INTEGRATE SEASONAL RAPTOR DISTRIBUTIONS INTO A BIRD AVOIDANCE MODEL FOR AIRCRAFT

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Military aircraft are particularly vulnerable to bird strikes as they routinely operate at low altitudes and high speeds. The U.S. Air Force (USAF) reports 3500 birdstrikes each year. These incidents have caused the loss of numerous jet aircraft, many with resultant fatalities and cost the USAF an average of over 65 million dollars each year (Merritt and Dogan 1992). The variety of birds struck by low-flying aircraft numbers in the hundreds, but raptors pose the most serious threat. Raptors are responsible for 46% of the damaging bird strikes (>$10 000) and Red-tailed Hawks (*Buteo jamaicensis,* 32%), Turkey Vultures (*Cathartes aura,* 31%), Black Vultures (*Coragyps atratus,* 13%), Golden Eagles (*Aquila chrysaetos,* 2%) and Broad-winged Hawks (*Buteo platypterus,* 2%) account for 80% of these. The disproportionate amount of raptor damage results because of the relatively large size of raptors and the fact that these birds make foraging and migratory flights at the same altitudes as military flight operations.

To reduce hazardous and costly bird strikes to aircraft, the USAF Bird Aircraft Strike Hazard (BASH) Team is developing a Bird Avoidance Model (BAM), which is designed to calculate the relative risk for an aircraft collision with a bird by integrating biological and geographical data into a Geographical Information System (GIS). Modeling for the USAF uses the Geographic Resource Analysis Support System (GRASS) GIS.

The BAM calculates the risk for striking a bird based on selected bird density and aircraft position criteria. The risk algorithm includes differing bird types by considering population densities, species weights and bird behavioral differences. The temporal aspects of hazard, including time of year (seasonal variation) and time of day (diurnal variation) with altitude distribution for each temporal component, are incorporated in the risk assessment. The GRASS output, provided to military flight and mission planners, contains a graphical depiction of bird hazards, a pictorial representation of the most serious concerns, and a text file with recommendations for aircraft operations in the vicinity of the hazard.

Geographically referenced population and migration dynamics data for waterfowl (ducks, geese and swans), raptors, cranes, pelicans, gulls and blackbirds were collected and entered into dBase III+ files. Most data files were developed from qualitative information, though databases such as the North American Breeding Bird Survey (BBS), Audubon Christmas Bird Count (CBC), Hawk Migration Association of North America (HMANA) and bird-banding recoveries were used to verify raptor distribution and abundance in the BAM.

BBS data were used to estimate summer populations for most raptor species. The BBS is a standardized survey conducted each year at 2791 point sites throughout the U.S. and Canada during the spring and early summer to index North American bird populations (Bystrak 1981). CBC data were used to distribute the winter populations for most raptor species. The CBC is a standardized survey of birds counted within a 15-mile diameter circle at 1500 locations on one day during 15 December–5 January (Bock and Root 1981). HMANA count data were used to determine the distribution of migrant raptors during different seasons and at various sites across the U.S. and Canada. Each species' population distribution was determined using HMANA data collected within respective regions selecting sites with good seasonal and hourly data for California and the Western, Central, Eastern and Atlantic Regions within 42–46°, 38–42° and <38° north latitude bands. Sightings per hour were converted to a percentage of each migrant population distributed within 2-wk periods.

Bird-banding recovery data maintained by the U.S. Fish and Wildlife Service provided additional information on fall migration pathways and wintering and migrating distributions. April–October banding and November–February recovery data were analyzed since birds should have already been in breeding areas by April, and birds banded at northern sites in October were just beginning their migration. There were limitations on using these data for some raptor species for various reasons: (1) a ban on vulture banding because of injuries resulting from excrement accumulating under the bands, (2) Broad-winged Hawks banded in relatively small numbers due to migratory habits and (3) insufficient direct recovery of banded Golden Eagles to construct migration pathways.

The BBS and CBC records are the only continent-wide bird population counts available, but cannot be directly compared since they are not collected with similar techniques and are somewhat qualitative. Despite these drawbacks, the surveys can be used to determine the relative abundance and distributions for common species in summer and winter. Actual population numbers in the BAM are not as important as the relative abundance among the migratory, breeding and wintering distributions.

The breeding bird population size and distribution for a raptor species was determined by distributing BBS data within 83 physiographic regions (Bystrak 1981), which were based on common soils, land use, natural vegetation, landforms and surface geology (U.S. Department of Agriculture 1981). The BBS summer population was calculated using the equation: $[\#R/(12.25 \times \#B)] \times A$, where #R is the sum of the number of birds seen in each region, 12.25 is the area of a single BBS route in square miles, #B is the number of BBSs in the physiographic region and A is the area of the region in mi^2. Once the breeding population was calculated, it was used as a population basis and other populations were expressed relative to it as follows:

Summer Population
= Breeding (BBS)
+ Nonbreeding (assumed 15%)

Late Summer Population
= Summer (Canada + U.S.) + Offspring

Resident Population
= Late summer
× %Nonmigrant (summer to winter band recoveries <50 mi)

Fall Migrant Population
= Late summer (Canada + U.S.) − Resident

Winter Population
= Fall migrant + Resident

Spring Migrant Population
= Fall migrant − 40% loss

Nonbreeding and offspring percentages of breeding populations for raptor species were obtained from published or survey data, or estimates based on similar species. Fall migrants and nonmigrants were apportioned to north latitude bands (42–46°, 38–42° and <38°). Migrant pathway populations reflected only migrant numbers within that latitude band and migrant density was decreased by the migrant wintering stopover number as the migration pathway extended southward. The migrant wintering stopover number was calculated from the percent nonmigrant in each latitude band. It was assumed that the winter residents which did not survive were replaced by migrant wintering birds, thus maintaining a stable resident population in the spring. The spring migrant populations were reduced by 40% from the fall migrant numbers.

Raptor altitude distributions for migrant and resident raptors came from radar data but were not available for all regions. Reports by Kerlinger (1985), Kerlinger and Gauthreaux (1984, 1985a, 1985b), Kerlinger et al. (1985), Cooper et al. (1988, 1989, 1990a, 1990b), Day and Byrne (1989), Hoffman (pers. comm.), Mindell (1984), Palmer (1988), Coleman and Fraser (1989) and Kelly (1992) were used to help develop the distributions for the BAM. A few examples of behavior used in the model are: (1) early spring arrivals reach northern states while snow is still on the ground, weather is cold and thermals are scarce; the birds should generally move at <200 ft above ground level (AGL) under these conditions; (2) resident Red-tailed Hawks have a preference for perch-site foraging rather than by soaring but can be expected to soar in areas with few perches and much lift from physical features; (3) Black Vultures spend more time flying higher than Turkey Vultures, watching as Turkey Vultures hunt by scent and lead the Black Vultures to carrion; (4) Resident Golden Eagles tend to feed early and late in the day, even though there is little thermal lift, when food sources are most active in the subdued light. Much more quantitative information is needed on altitude distributions, which are an important component in the BAM.

EXAMPLE DATA

Although Red-tailed Hawks, Turkey Vultures, Black Vultures, Golden Eagles and Broad-winged Hawks were all included in the BAM, results and summaries from data analyses for all species are

Table 1. Comparison of Red-tailed Hawk migration distances by region of the U.S.

REGION	NUMBER BAND RECOVERIES	MEAN DISTANCE (mi)
California	41	75
Western	44	229
Central	85	475
Eastern	256	399
Atlantic	172	243

Table 2. Comparison of migration distances of Red-tailed Hawks in the U.S. by latitudinal bands based on band recoveries.

LATITUDE BAND	NUMBER RECOVERIES	MEAN DISTANCE (mi ± SD)
42–46°N	402	420 ± 356
38–42°N	161	211 ± 248
<38°N	72	84 ± 119

too lengthy to include in this paper. Since the analyses are similar, only the red-tail data are described here, with brief mention of the other species.

Red-tailed Hawk Populations (U.S.). Using BBS data I estimated the U.S. population of red-tails to be 800 000 hawks. In summer, the population grew to an estimated 920 000 hawks and in late summer it increased to an estimated 1 520 000 hawks (>42° = 456 000, 38–42° = 304 000 and <38° = 760 000 hawks). The resident population of red-tails was estimated to be 637 000 (>42° = 87 000, 38–42° = 109 000 and <38° 441 000 hawks). The population of fall migrants was estimated to be 2 328 000 hawks (>42° = 936 000, 38–42° = 739 000 and <38° = 653 000 hawks). Winter populations were estimated to be 1 568 000 hawks (>42° = 220 000, 38–42° = 447 000 and <38° = 901 000 hawks). The spring migrant population was 1 430 000 hawks (>42° = 562 000, 38–42° = 476 000 and <38° = 392 000 hawks).

Chronological Distribution of Migrants. HMANA data indicated that the major migratory movement of red-tails was between 10 October–13 November. Since there are regional and latitudinal differences (e.g., peak passage of red-tails in the western region was 2–3 wk earlier than in other regions), the migrant chronology was estimated as the percentage of migratory population movements per 2-wk period, through three latitude bands and 14 regions.

Migration Pathways. Analysis of direct (same year) banding recovery data provided the best picture of Red-tailed Hawk fall movements. Migration distances were compared for Pacific, Western, Central, Eastern and Atlantic Regions (Table 1), with red-tail migration starting in northern (>42°), middle (38–42°) and southern (<38°) latitudes (Table 2). Movements of <50 mi were separated by region and latitude band (Table 3) to indicate nonmigratory birds.

These broad analyses to determine the percentage of the Red-tailed Hawks that are migratory confirmed findings from investigations with smaller samples. The most northern Red-tailed Hawks (>42°) are migratory whereas populations in the middle latitudes (38–42°) are only partly migratory and southern populations (<38°) are permanent residents (Brinker and Erdman 1985). More detailed data were available within some latitude bands. For example, recoveries of red-tails banded in California indicated that these birds are partial or nonmigratory, and birds banded in the Pacific Northwest are nonmigratory. In contrast, red-tails banded inland in the Northwest, away from the moderating Pacific influence, migrated long distances with fall frontal winds and were sometimes recovered in California.

Better data were needed to distribute count data throughout migration pathways defined by band recoveries. Leading lines may have accounted for only a small proportion of the migratory pathways of raptor populations in the U.S. since there are few long ridgelines and coastlines that are appropriately oriented for migration. Some experts (Kerlinger et al. 1985) think too much emphasis has been placed on concentration zones associated with ridges, since mountain ranges may only have a local influence within 10 km. Red-tails may move

Table 3. Comparison of numbers of migratory and nonmigratory Red-tailed Hawks in the U.S. by latitudinal band.

	42–46°N	38–42°N	<38°N
Migrant	327	103	30
Nonmigrant	76	63	42
Total observations	402	161	72
Percent nonmigrant	19	36	58

along ridgelines when stable updrafts are generated but generally have a low affinity for following leading lines. Radiotelemetry studies have revealed that Red-tailed Hawk migration occurs on a very broad front (>70% of the time hawks migrated away from ridges). Some experts think that strong fall winds in the east tend to concentrate raptors toward the coast (Kellogg pers. comm.). Winds together with the Appalachian Mountain chain may account for this concentration as indicated by banding data.

Banding recovery and HMANA data indicated that Red-tailed Hawks migrate mostly on a broadfront, but that barriers to migration, especially the Great Lakes and the Atlantic Ocean, tend to concentrate red-tails and other raptors. Concentration zones in the BAM were based on HMANA count data and were expressed as two, three, and four times the normal regional and latitudinal distributions. Migratory movements were assumed broad-frontal throughout the latitudinal regions and on dispersal from concentration zones.

Red-tailed Hawk altitude distributions for the 38–42° latitude band were summarized for residents and five migrants. Altitude distributions were developed for ideal migrating conditions. For example, on days when good lift is available for soaring, 73% of red-tails (and other *Buteos*) should occur between 1001–2000 ft. In cloudy conditions when there are not sufficient thermals, fewer *Buteos* may migrate, which would present a conservative condition in the BAM. Nevertheless, such migration as does occur could be mainly at 0–1000 ft, which increases the risk. The solution would be thermal prediction, but this would require BAM users to input weather data and is probably 5 yr away.

OTHER SPECIES

Broad-winged Hawks are included in the model because large, predictable flocks concentrate along geographical leading lines. These birds tend to flock while migrating even away from recognized concentration zones, and are therefore potentially hazardous to aircraft. However, HMANA data indicate that the major broad-wing movements are within 2-wk periods (approximately 23 April–7 May and 12–26 September) and do not present as serious a year-round hazard to aircraft as red-tails and vultures. Migratory broad-wing concentrations (from HMANA counts) result when one half or more of the population funnels into four relatively narrow corridors around or between the Great Lakes. In the southern U.S. nearly the whole broad-wing migration population goes around the Gulf of Mexico overland. Broad-wing migration can be summarized as follows: (1) it conforms to four travel lanes controlled by the Great Lakes corridors; (2) in the eastern U.S., there is a wide lane that uses chiefly the updrafts of the Appalachian ridges; (3) in the central U.S., there is a wide pathway between the Mississippi River and the edge of the High Plains; and (4) in the center of the U.S., all broad-wings converge on south Texas in fall and diverge in spring northward.

Turkey Vultures, like Red-tailed Hawks, are widely distributed with large populations (late summer = 3 717 000 vultures). Their summer distribution encompasses virtually the entire continental U.S., while the winter range is generally restricted to the southern and coastal regions. The wide distribution of this species together with its soaring behavior make it and red-tails the raptors most commonly encountered by USAF aircraft. Unfortunately, banding data are essentially nonexistent and HMANA observers often discount vultures because they are uncertain if the birds are migratory or residents. Information on distribution and migration of this species, of such importance to the BAM, is therefore essentially qualitative. However, it seems that Turkey Vultures may move on a broad front to an even greater extent than red-tails, since they are less dependent on ridge lift and wind conditions (Kellogg pers. comm.), and are remarkably adaptable to local conditions. They are generally lowland migrants and travel on thermals up to several thousand feet. In the east, migration is essentially a shift within the Canadian–U.S. breeding range, although some eastern birds may reach Latin America via the Florida Keys. In western North America, Turkey Vultures presumably migrate to Mexico, Central America and South America. There are now plans to use satellite spectral imagery to correlate physiographic, geographic and climatic correlates to model the breeding and wintering distributions of Turkey Vultures in the continental U.S. (DeFusco 1993). This approach may be very valuable for BAM estimates in the future.

Black Vulture population distribution is somewhat limited and is essentially nonmigratory in the U.S. Data indicate that populations shift (migrate) relatively short distances and are more abundant southerly and toward coasts. Since migration periods are relatively short and migration paths are difficult to define, I did not incorporate migration pathways into the BAM.

There is insufficient banding data for Golden Eagles to construct migration pathways but seasonal populations probably concentrate in states with ideal habitat. Data also suggest that migrants in the western U.S. move southeasterly with fall frontal winds and, in the east, follow the Appalachians tending to remain within preferred habitat. Migratory pathways in the BAM were based on the occurrence in physiographic regions of habitat preferred in the BBS distribution.

WEATHER

Wind direction, wind velocity, cloud cover, air temperature, barometric pressure and visibility all seem important during both spring and fall migrations (Heintzelman 1986). Considerable qualitative information has been published on weather effecting migration. Low barometric pressures north of a site triggers fall migrations and the passage of cold fronts aids migrations by producing favorable winds (Haugh 1972, Richardson 1978, Millsap and Zook 1983). Strong migrations usually continue 1–3 d following frontal passage (Heintzelman 1986). Fall migrations are dependent on local weather conditions but the general weather conditions are considered more important (Hoffman 1981, 1982). Spring migrations are much less studied but Haugh (1972) suggested that warm front coupled with low pressure to the north and west triggered large migratory movements. However, it is not practical to include weather in the BAM until its effects on migration are more thoroughly defined.

THE FUTURE

Distributing BBS and CBC counts throughout physiographic regions was a convenient way to model population densities in the GIS. However, bird distributions may be refined in the BAM if vegetation, water, ridges and land use correlate with winter, summer and migration densities. For example, a low-level route with a typical 8-mi width may have agricultural crops, water and terrain providing lift for raptors within or near the route which could concentrate migrants or attract wintering stopover birds. The BAM provides the historical migrant pathways and seasonal population distributions, while satellite imagery will add a predictive habitat component.

The GRASS GIS BAM for the continental U.S. will be operational in October 1993. A model is underway for Alaska and a global one is planned. Data from Europe indicate that over 35% of USAF birdstrikes occur during low-level exercises, but the BASH Team has no way to assess potential bird hazards in Europe. Moreover, deployments in the Middle East and Africa have emphasized the need to identify hazardous areas and times for the massive spring and fall migrations. We have begun a search for bird migration and concentration information for Europe, Africa and the Middle East to include raptor, waterfowl, pelican, stork and gull ringing, wintering, breeding, altitudinal and chronological distributions.

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